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Title: UNIVERSITY PROGRAMS OF THE ADVANCED FUEL CYCLE INITIATIVE
FISCAL YEAR 2002 ANNUAL REPORT

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University Programs of the Advanced Fuel Cycle Initiative
Fiscal Year 2002 Annual Report

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Abstract–*As the Advanced Accelerator Applications (AAA) Program, which was initiated in fiscal year 2001 (FY01), grows and transitions to the Advanced Fuel Cycle (AFC) Program in FY03, research for its underlying science and technology will require an ever larger cadre of educated scientists and trained technicians. In addition, other applications of nuclear science and engineering (e.g., proliferation monitoring and defense, nuclear medicine, safety regulation, industrial processes, and many others) require increased academic and national infrastructure and even larger student populations. Because of the recognition of these current and increasing requirements, the DOE began a multi-year program to involve university faculty and students in various phases of these Projects to support the infrastructure requirements of nuclear energy, science and technology fields as well as the special needs of the DOE transmutation program. Herein I summarize the goals and accomplishments of the university programs that have supported the AAA and AFC Programs during FY02, including the involvement of more than 115 students at 30 universities in the U.S. and abroad.*

I. INTRODUCTION

Students and faculty alike view P&T--Partitioning of used nuclear fuel and Transmutation of its resultant wastes--as an exciting and ripe area for academic research. Large-scale research for P&T technology began in the U.S. in the early 1990s as a Laboratory Directed Research and Development Project (LDRD) at the Los Alamos National Laboratory. Researchers at LANL first examined molten-salt fueled and cooled systems for Accelerator-driven Transmutation of Waste (ATW), and later investigated liquid-metal-cooled, metal-fueled ATW concepts. The National Academy of Sciences reviewed ATW concepts as a means of managing used nuclear fuel in the mid-1990s,[1] and the Department of Nuclear Engineering at the Massachusetts Institute of Technology reviewed the ATW LDRD project of LANL again in 1998. Following the MIT review the U.S. Congress recognized the potential of this technology for managing a large legacy of used nuclear fuel; they then authorized the DOE Office of Environmental Management (Office of Civilian Radioactive Waste Management-OCRWM) to develop a technology and deployment roadmap in FY99. Congress then funded an ATW research program within the Office of Nuclear Energy, Science and Technology (DOE-NE) in FY00. A year after the completion of the ATW Roadmap, the Advanced Accelerator Applications (AAA) Program was initiated as a multi-laboratory research program in collaboration with a number of universities, including the University of Nevada, Las Vegas, the University of California at Berkeley, the University of Michigan, and the University of Texas at Austin. The primary mission of the AAA Program was the development of technology for transmutation of nuclear waste and demonstration of its practicality and value for long-term waste management. Other goals were to help revitalize the U.S. nuclear infrastructure and for the U.S. to resume an international leadership role in nuclear technologies. This new science and technology will require a large cadre of educated scientists and trained technicians in addition to that required for our broader national nuclear infrastructure.[2, 3] The AAA program is now transitioning to a new program called the Advanced Fuel Cycle Initiative (AFCI or AFC), with a larger goal of integration and management of nuclear materials in the entire fuel cycle. This larger program will require an even larger involvement of academia and students than the ATW and AAA projects did.

During the next decade, the nation will need additional nuclear scientists and engineers for national security programs like counter-proliferation, global monitoring activities, stewardship of our nuclear stockpile, and naval nuclear propulsion. We will also need more college graduates for design and federal regulation of Generation IV reactors and fuel cycles,[4] and we will need young people for nuclear medicine and medical research using radioisotopes. We will need still more for expanding industrial radiation applications such as manufacturing, oil and

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gas exploration, and irradiation to sterilize hundreds of consumer products and most medical equipment. In addition, we ll need a larger nuclear workforce for irradiation of food as well as livestock feed to eliminate pathogens like Listeria and E. coli from our food, Hoof-and-mouth from our feed stocks, and Anthrax from our mail.

Because of the requirements for educated scientists and engineers in a wide variety of nuclear- and accelerator-related fields, first the ATW, then the AAA, and now the AFC project have multi-year programs to involve university faculty and students in various phases of these projects. This report describes ongoing university programs and new initiatives that are supporting both the research needed for transmutation and the national nuclear infrastructure. These past programs include ATW research projects at the University of Michigan, the University of California at Berkeley, and the University of Texas at Austin; a University Participation Program (AAA UPP) at the University of Nevada, Las Vegas (UNLV), and a University Fellowship Program (AAA UFP). Current programs include ongoing LANL-funded university research, including four more universities that were added this year, the UNLV program, which has been renamed the UNLV Transmutation Research Program (TRP), the AFC Fellowship Program, and a new project at the Idaho Accelerator Center, a research center at the Idaho State University. This report begins with a description of student support during the year. More detailed descriptions of research programs at the universities are in a later section.

Students who were supported by the AAA Project made up about half of those who participated in the first ANS Student Mini-Conference that was imbedded in the 2001 Winter Meeting of the American Nuclear Society. AAA students presented more than half the papers, which insured the success of this inaugural Student Mini-Conference. In this photo the LANL University Programs Leader presents an overview of the AAA Project to Mini-Conference participants. (Photo courtesy of UNLV)

II. AAA STUDENT SUPPORT

A significant aspect of these Programs is that they have supported a substantial U.S. student population. During FY02 more than 115 students were supported through the University Fellowship Program, the UNLV TRP, research contracts with five universities, and internship programs at national laboratories. This year, FY01 and FY02 AAA funding supported students. In addition, students worked on transmutation-related research with support from other DOE programs (special student programs, other research projects, etc.). Table I. is a summary of the different categories of student support, and the following sections briefly describe the programs.

Table I.
Summary of FY02 AAA Student Support

UNLV Transmutation Research Program	49	(26 graduate and 23 undergraduate students)
ISU-IAC Program	20	(10 graduate and 10 undergraduate students)
AAA University Fellowship Program	20	(10 FY01 and 10 FY02)
Directed University Research Programs	14	
Laboratory interns	21	(includes students also in other categories)
Seaborg Transactinium Science Institute Summer School	2	

II.A. UNLV Transmutation Research Program

Students at UNLV are employed in research projects and as support to the project administrators in the Harry Reid Center for Environmental Studies (some of this support to administrators is technical in nature, however). Sixteen approved research projects, which are described in a later section of this report, included 23 undergraduate and 26 graduate (Masters and Ph.D.) students. A complete discussion of the program is in the first TRP annual report.[5] These students were from several colleges at UNLV, including Health Sciences, Engineering, and Sciences, and from several departments within those colleges. The research projects at UNLV are highly interdisciplinary, cutting across departments and even colleges. With the Transmutation Research Program now in its second year, the UNLV has become the lead U.S. university for transmutation research. UNLV graduated two students who were supported by this program with M.S. in Mechanical Engineering degrees.

UNLV students, faculty, and staff during a weekly Materials Science Research meeting. (Photo courtesy of UNLV)

II.B. ISU Idaho Accelerator Center

Part of the growth of university programs of the AFC project was the addition this year of a new program at the Idaho Accelerator Center (IAC) of the Idaho State University (ISU). This program included a number of intercollegiate collaborations as well as improvements to equipment and infrastructure at ISU. The AFC program at ISU-IAC supported twenty students, including two from the Republic of Georgia who are studying at ISU. This project also included three collaborations with UNLV, and one UNLV student worked in the IAC during the year.

ISU undergraduate student, Jason Marenda, operates the 20-MeV linac at the Idaho Accelerator Center. UNLV graduate student Suresh Sadineni is in the background. (Photo courtesy of ISU-IAC)

II.C. University Fellowship Program

The AFC University Fellowship Program (AFC UFP), also in its second year, is managed for DOE/NE by University Research Alliance, which is a consortium of Texas universities (URA is located in Amarillo, Texas). The University Fellowship Program is intended to support top students across the nation in a variety of disciplines that will be required to support transmutation research and technology development in the coming decade. The program was described in detail at the 2001 Winter Meeting of the ANS.[6] In the first year, ten Fellows were selected from a large pool of highly qualified applicants. The Fellowships were awarded in April of 2001 to students who would attend graduate school at the University of Illinois-Urbana/Champaign, the Massachusetts Institute of Technology, the University of Texas-Arlington, the University of California-Berkeley, the University of Massachusetts-Lowell, the University of Texas-Austin, The Ohio State University, Texas A&M University, and the Chemical Engineering and Nuclear Engineering

Departments of the University of Michigan. All of these students have been supported by AAA-AFC funding during the past year, and two have already been graduated, one by MIT and the other by UT-Austin, with master s degrees in Nuclear Engineering.

The selection of ten more fellows in April of 2002 added six more universities to the Fellowship program: Georgia Institute of Technology, the University of Florida, the University of Illinois at Chicago, North Carolina State University, the University of New Mexico, and the University of Tennessee at Knoxville. These AAA Fellows will work on a variety of topics as they conduct research for their Masters theses and degrees.

Both the FY01 and FY02 Fellows collaborated directly with technical staff at the National Laboratories to formulate their Masters thesis topics so that they will directly benefit the AFC Project. To facilitate selection of thesis topics, a summary of research topics that were appropriate for M.S.-level research was developed.[7] During the summer of 2002, seven of the Fellows chose to work at five different National Laboratories: Los

The AAA fellowship program provides highly talented young people with their first opportunities for professional networking. These 2002 AFC Fellows are gathered for a meeting with Nevada Senator Harry Reid, who invited them for breakfast, while the fellows were in Washington DC for meetings with DOE program officials.° (Photo courtesy of URA)

Nine 2001 AAA Fellows stood outside the White House with Project Director John Herczeg during their introduction to the AAA Program. MIT graduated Leigh Outten (second from the right) in May 2002 with a Master of Science in Nuclear Engineering degree following her studies on applying decision analysis techniques to select a desirable master logic diagram to identify major safety concerns for potential accelerator systems. The University of Texas graduated Coy Bryant, (fifth from right) in May 2002 with a Master of Science in Nuclear Engineering degree following his studies on developing computer models for solvent extraction processes for optimizing flow sheets for actinide transmutation and analyzing their technical benefits/liabilities and proliferation resistance. (Photo Denis Beller)

Alamos, Argonne, Argonne-West, Oak Ridge, and Sandia. Students worked on a variety of projects, for instance: at LANL conducting an experiment to measure neutron multiplicity in lead and lead-bismuth targets for high-energy proton accelerators; at ANL-West on a project to develop fabrication technology for transmutation fuels; at ANL on separations of used fuel using pyro-chemistry technology; and at ORNL on fabrication of coated-particle fuels.

Two of the FY01 Fellows have completed their master s degree programs, and eight FY01 Fellows are now completing their M.S. theses in preparation for graduation. These students will be prepared to work at the labs in the coming years, entering with a good understanding of the big picture and a comprehensive knowledge of technology needs in their respective areas of interest.

II.D. Laboratory Intern Students

The national laboratories employ students, from undergraduate to Ph.D., to provide administrative assistance and to conduct critical scientific research. Most interns conduct research during the summer, however, several students are supported during other portions of the year, and Ph.D. students may work at the laboratories year-round. Four of the AFC National Laboratories supported 21 undergraduate and graduate students directly during the past year (6 at ANL, 2 at ANL-West, 10 at LANL, 2 at LLNL, and 3 at ORNL). This total includes four of the AAA Fellows who were mentioned previously in the AAA UFP Students section. The two students who were at LLNL attended Summer School in the Glenn T. Seaborg Institute for Transactinium Science (GTS-ITS).

II.E. AAA Directed University Research Students

Several students conducted AAA research at Michigan, Berkeley, Texas, North Carolina State, Arizona State, and the Imperial College of London. A total of fourteen students have been supported by these Directed University Research projects. Individual work at these universities is described in a following section.

III. CURRENT UNIVERSITY RESEARCH

During FY02, academic participation in the Advanced Accelerator Applications (AAA) Program increased from about \$4 M in FY01 to more than \$7 M in FY02 with a large increase in the UNLV budget, the addition of another major new university program at the Idaho Accelerator Center of Idaho State University, and expansion of other university programs. An integral component of the AAA Program is continued Directed University Research at Berkeley, Michigan, and Texas. This continued research leverages the Project s prior investment in computer systems, software, and other resources and in faculty expertise, and it gives us the opportunity to increase the value of research conducted by faculty and students at these institutions. In the following sections, ongoing university research in the Directed University Research programs is highlighted, along with 16 research tasks at the University of Nevada, Las Vegas and at the ISU-IAC.

IV. DIRECTED UNIVERSITY PROJECTS

In FY00 the Accelerator-driven Transmutation of Waste (ATW) Project began as a \$9M effort following a decade of laboratory-funded research at Los Alamos National Laboratory. During the ATW Project, Los Alamos National Laboratory contracted with three universities the University of California-Berkeley, the University of Michigan, and the University of Texas-Austin to support ongoing research in transmuter design and analysis, in planning for experiments, and in assessing proliferation-resistance attributes of separations and transmutation technologies. Research projects at these three universities have continued, and they have employed undergraduate and graduate students during several years. In FY02 LANL added two more university programs at North Carolina State University and the University of Illinois at Urbana Champaign. In addition, ANL began a project at the University of Michigan and LANL initiated purchase requests for research support from the University of Florida and the Georgia Institute of Technology (these contracts were not signed during FY02, so they will not be described herein). In all, LANL supported 15 students at 5 universities, and ANL provided partial support to 2 students (the total remains 15 students).

IV.A. University of California at Berkeley

Faculty and students at the University of California-Berkeley have conducted research to evaluate designs of transmuters and to optimize the destruction of neptunium (the isotope of primary concern for long-term storage).[8] They have evaluated designs of various molten-salt reactors and their potential for transmuting actinides and problem radioisotopes. If one could be built economically, a molten-salt transmuter with continuous removal of all fission products offers a remarkably high fractional transmutation, greater than 90 percent. Conclusions of analysis

UC Berkeley students at the 2002 ANS Student Conference in Philadelphia. Darby Kimball, who is working on an AFC research project funded through LANL, holds the Best Student Paper award. (Photo courtesy of UC Berkeley)

of molten-salt and other transmutation reactors are discussed in a paper that was presented at the Nov. 2001 Winter Meeting of the American Nuclear Society in Reno, NV.[9]

Several faculty members and students have been supported by both FY01 and FY02 AAA funds while conducting research for or connected to the AAA R&D efforts. In addition, several students have worked on code systems that have directly benefited AAA research needs while supported by funding from other programs, such as the Nuclear Energy Research Initiative (NERI), the Nuclear Engineering Education Research program (NEER), and Generation IV roadmap and reactor studies projects. One example of this synergy was a project to compare lead-bismuth-cooled and sodium-cooled transmuter systems,[10] and another was a project to evaluate a modular, pebble-bed-type gas-cooled reactor as a transmuter.[11]

IV.B. University of Michigan

At the University of Michigan, several faculty and students have supported the ATW Project with studies for the design of integral experiments as well as evaluations of a variety of technical issues. Faculty members have acted as honest brokers to provide comments and advice during systems studies, reactor studies, and the development of concepts for future experiments. In addition, students have completed considerable work and thesis studies. In one study, mono-energetic neutron sources of sufficiently high energy (e.g. 14 MeV) to contribute to the science of accelerator-driven transmutation in lead and bismuth moderators have been shown to produce flux depressions just below the source energy, such that they would contribute marginally to physics measurements and benchmarking in the energy regime of the depression.[12] This work continued in FY02 with the examination of the ability of standard fast spectrum analysis techniques to capture the details of neutron slowing down in heavy moderators such as Pb and Bi.[13] In another project neutronics tools were compared to validate design methods.[14]

University of Michigan students (from left to right) Jim Platte, Reuben Sorensen, Victoriya Kulik, and Jeffrey Davis during a research meeting. Platte has been involved in three different aspects of the AFC Program: he spent the summer as a LANL Intern conducting and analyzing a neutron target experiment at LANSCE, he is a 2001 AAA Fellow, and he has supported work for the LANL-U of Michigan contract for Transmutation Sciences research. (Photo courtesy U of Michigan)

As one of the major tasks for the AAA project at the University of Michigan, they have been studying dynamic behavior of accelerator-driven subcritical reactor (ADS) systems. This has involved the development of dynamic models for simulating multiple pulses of spallation neutron sources and methods for determining the reactivity in ADS systems. Their emphasis has been on developing computational tools that can accurately and efficiently represent the localized nature of spallation sources in determining the power distribution and reactivity in transient conditions. A Michigan student developed numerical algorithms based on a two-dimensional time-dependent diffusion theory code that can accurately account for step changes in localized sources in time to establish a space-dependent dynamic model for simulation of ADS transient behavior.[15] This involves separate treatments for the shape-function and amplitude-function calculations that can represent prompt space-time variations in neutron flux within the quasi-static formulation. These studies continued in the development of methods to account for the spatial dependence in reactivity measurements.[16] Other work at Michigan has included the development of a linear reactivity model[17] and extrapolation algorithms for equilibrium cycle analysis of transmutation systems, integral experiments for fuel reaction rate, and advice on the prioritization of research requirements.

LANL technical staff initiated a new project at U of Michigan in FY02. This project involves the use of proton irradiation to simulate spallation-neutron radiation damage in accelerator-driven systems. This work began with an investigation of the effect of higher gas production at significant doses (several displacements per atom or dpa) to lay a foundation for a full-scale irradiation campaign. It was followed by development of a detailed description of the irradiation campaign (temperatures, dose rates, doses, and He-implantation levels), and finally by conducting irradiation testing on steels at various dpa levels. The campaign is about half finished, with proton irradiations of HT-9 and T-91 steels at 3.0, 7.0, and 10.0 dpa having been completed.

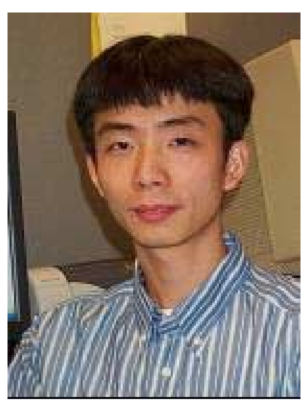
IV.C. University of Texas at Austin

In one of the two research projects that are ongoing at UT-Austin, proliferation resistance and security metrics have been quantified for separations, fuel fabrication, transmutation, and disposal.[18] They developed of a set of high-level metrics by consulting a number of experts in the field. This year they have added time-dependence to the methodology as well as uncertainty estimates. A product of this work is an initial comparison of the security metric from transmutation with that from the once-through fuel cycle.[19] In another project, UT-Austin is preparing to conduct and analyze the results from a set of experiments at the LANSCE facility at LANL. In conjunction with LANL technical staff, they will conduct hydrogen and helium implantation experiments to determine proton-induced damage. One faculty member and several students have participated in these research projects during FY02, during which they were supported by both FY01 and FY02 AAA funds.

UT Student Coy Bryant contributed to two AFC/AAA Programs. While supported by the FY01 AAA Fellowship Program he assisted in a LANL-funded UT-Austin project to quantify proliferation resistance of various fuel cycles. (Photo courtesy URA)

IV.D. North Carolina State University

A new participant in the international collaborations for the AAA Program was added in the latter part of the year. North Carolina State University is calculating radiation damage, including production of displacements, helium, hydrogen, and heavier transmutation products, and energy deposition in targets for generation of high-energy spallation neutrons. They are examining response in target materials, containment structures, and entrance windows of the target assemblies for the SINQ spallation neutron sources that are under design and development at the Paul Scherrer Institute (PSI). These targets include the Mark II and Mark III designs. In addition, they will examine less obvious (and less well studied) mechanisms for the transfer of energy to the irradiated materials and hence the production of displacements. These mechanisms include recoil-atom damage and other interaction products. Finally, they will analyze the effects of the calculated radiation



NCSU graduate student Wei Lu is calculating radiation damage to materials in spallation neutron sources. During summer 2002, he served as a Research Associate at the Paul Scherrer Institute in Switzerland, where he conducted radiation damage calculations on materials for Target 5 at the SINQ Spallation Neutron Source facility. (Photo courtesy of NCSU)

damage on mechanical and other property changes and assess reasonable and safe lifetimes for radiation-damaged components. Much work has been completed in the short time since the initiation of this project.[20]

IV.E. University of Illinois at Urbana Champaign

A 2001 AAA Fellow at UIUC has begun a thesis project to investigate impedance spectroscopy as a feasible method of measuring the effects and rates of lead-bismuth corrosion on structural materials while DELTA-Loop research staff members at LANL provide advice and collaboration. Through a contract with LANL, UIUC will purchase components for and construct a container/piping system to investigate issues related to corrosion in high-temperature liquid lead-bismuth eutectic (LBE). In this impedance spectroscopy technique, alternating electric currents of various frequencies will be used to measure the electrical impedance of a surface corroded by lead-bismuth. UIUC will construct a lead-bismuth loop (piping, connections, thermocouples, pump(s), heating element(s), lead-bismuth, and experimental section) at the Materials Research Laboratory (UIUC MRL), and will conduct controlled experiments to take impedance spectroscopy measurements on corroding steel samples.

V. UNLV TRANSMUTATION RESEARCH PROGRAM

The UNLV Transmutation Research Program (TRP) was designed to benefit the National AAA Project and the University s goals to enhance student-focused and internationally recognized research programs. In accordance with the public law that established the AAA Project and the UNLV funding, the UNLV TRP included research and development of technologies for economic and environmentally sound refinement of used nuclear fuel. In its first year, 12 research projects were initiated, and that list expanded to 16 during FY02. Student-conducted research is well on its way, already contributing substantially to research for LANL and ANL. In addition, substantial improvements to infrastructure at the UNLV are underway (for details see Reference 5).

The strategic plan to accomplish the objectives of TRP management and university administrators has the following three main components:

1. Program Support to ensure the smooth operation of the UNLV UPP and all non-research functions such as maintenance of communication links and information management, organization of workshops and conferences, and administration of the competitive proposal process;
2. Research Infrastructure Augmentation under which the UNLV nuclear research infrastructure is being enhanced through the hiring of new researchers and the acquisition of scientific equipment to allow researchers to perform more AAA-relevant research on campus; and,
3. Student Research to support projects at UNLV on tasks relevant to TRP research and technology development needs.

The Director of the UNLV TRP has provided quarterly reports, has submitted an overview report to a national conference,[21] and has given presentations at reviews and national meetings that describe the vision and implementation of this new program. These presentations and reports include descriptions of the research projects that were underway in the first two years of the program, important decision points, and a new paradigm in grant research exemplified by the program.

To initiate these research projects, UNLV hosted technical staff from the national laboratories in a series of seminars and technical working meetings. The seminars were conducted on an almost-weekly basis to expose the faculty at UNLV to the widest possible array of TRP research needs. The purpose of these seminars and visits was to develop collaborative research projects where the lab technical staff and the UNLV faculty and students would work together directly. Staff from ANL visited several times and presented seminars to develop research projects on used-fuel separations, staff from LANL visited to develop accelerator projects and materials research projects, and staff from ANL-W visited to develop research projects related to transmutation fuels and fuel fabrication.

To illustrate the breadth of ongoing research at UNLV, these projects are listed and described below by UNLV Task Number:

1. Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides is a project in the UNLV Mechanical Engineering Department that is being conducted in collaboration with Argonne National Laboratory-West. In this project students will investigate methods and equipment to cast fuel pins for transmutation while preventing the evaporation of volatile actinides such as americium. The Principal Investigator (PI) is Prof. Y. Chen, and the laboratory collaborator is Mitchell Meyer (ANL-W).

2. Modeling, Fabrication, and Optimization of Niobium Cavities is a collaboration between the Department of Electrical and Computer Engineering, the Department of Mechanical Engineering, and the AAA Technology Project Office (Superconducting RF Engineering Development and Demonstration). In this project researchers will perform research to maximize the performance of the accelerator cavities by studying multipacting (a localized resonance process resulting from the impact of electrons on cavity surfaces), by studying the effect of chemical etching on cavity surface roughness, and by redesigning cavities. The PIs are Prof. R. Schill and Prof. M. Trabia and the laboratory collaborator is K. C. D. Chan (LANL).
3. In a project titled Experimental Investigation of Steel Corrosion in Lead Bismuth Eutectic: Characterization, Species Identification, and Chemical Reactions, UNLV Physics Department faculty and students initiated a program to investigate experimentally the corrosion of steels by Lead-Bismuth Eutectic. Corrosion products and related chemical reactions will be identified using facilities at UNLV for the Scanning Electron Microscope (SEM) and x-ray diffraction (XRD). Thirty samples of steel now at UNLV were exposed to high-temperature LBE and have been analyzed by Russian scientists. Several samples have been examined with the SEM, and the most recent experimental results were reported at the ANS Winter Meeting in Reno.[22] The PI is Prof. J. Farley and the laboratory collaborator is Ning Li (LANL).
4. Researchers in the Department of Mechanical Engineering will investigate Hydrogen-Induced Embrittlement of Candidate Target Materials for Applications in Spallation-Neutron-Target Systems, Phase I with LANL scientists and engineers. The PI is Prof. A. Roy and the laboratory collaborator is Ning Li (LANL).
5. Modeling Corrosion in Oxygen Controlled LBE Systems with Coupling of Chemical Kinetics and Hydrodynamics is an effort to develop a better understanding of the physical chemistry of lead, lead-bismuth, and structural materials. The PI is Prof. S. Moujaes, and the laboratory collaborator is Ning Li (LANL).
6. Neutron Multiplicity Measurement for AAA Target/Blanket Materials involves a collaboration with the Khlopin Radium Institute in St. Petersburg Russia and future measurements with proton-neutron sources (accelerators) at UC Davis and LANSCE. The PI is Dr. C. Hull, and the laboratory collaborator is Eric Pitcher (LANL).
7. UNLV has begun an intercollegiate project to Develop Dose Conversion Coefficients for Radionuclides Produced in Spallation Neutron Sources. The PI is Prof. P. Patton, and a working group has been formed with participants from Georgia Tech, Idaho State, Univ. of Florida, and UT-Knoxville/ORNL. The laboratory collaborator is Keith Eckerman (ORNL), who has been appointed to an Adjunct Professor position at UNLV.
8. Development of a Systems Engineering Model of the Chemical Separations Process, is a project to accelerate the development of the AMUSE code for modeling aqueous separation of used nuclear fuel. The PI is Prof. Y. Chen, and the laboratory collaborator is James Laidler (ANL).
9. In a project titled Design and Evaluation of Processes for Fuel Fabrication, PI Prof. G. Mauer is investigating the remotely operated manufacturing processes for a variety of fuel fabrication schemes. The laboratory collaborator is Mitch Meyer (ANL-W).
10. Development of a Mechanistic Understanding of the High-Temperature Deformation of Alloy EP-823 is a project to examine a particular alloy of steel that might be used in spallation targets. The PI is Prof. A. Roy and the laboratory collaborator is Stuart Maloy (LANL).
11. Prof. W. Culbreth began and completed Nuclear Criticality Analysis for the Transmuter Fuel Fabrication and Reprocessing Process. This project was so successful that the initial work scope of the project was completed in the first year. The students are continuing to apply models generated through this work to analyze new design configurations in collaboration with ANL technical staff. Due to cost savings implemented by the program, carry-forward funding from the first year will be sufficient to support the students supporting this effort (additional funding has not been requested for this project). The laboratory collaborator is George Vandegrift (ANL).
12. Radiation Transport Modeling of Beam-Target Experiments for the AAA Project, supports modeling of LANSCE experiments with the MCNPX code. Prof. W. Culbreth leads this effort, his students work at ISU-IAC and LANSCE during the summer, and the laboratory collaborator is Ray Klann (ANL).
13. Developing a Sensing System for the Measurement of Oxygen Concentration in Liquid Pb-Bi Eutectic is a project to further development of LBE-cooled reactor systems and proton targets. The PI is Prof. Y. Jiang and the laboratory collaborators are Ning Li and Tim Darling (LANL).
14. Use of Positron Annihilation Spectroscopy for Stress-Strain Measurements, is collaboration with ISU-IAC to evaluate a new materials science technique to evaluate residual stress in worked or welded materials. Positrons are created inside the bulk material by high-energy gamma rays that have been produced during the deceleration and stopping of high-energy electrons (Bremmstrahlung) from a linac at the IAC. Prof. A. Roy is the PI, and collaborators are Stuart Malloy (LANL) and Prof. Doug Wells (ISU-IAC).

15. In collaboration with the Khlopin Radium Institute in St. Petersburg, Russia, Prof. S. Steinberg is examining Immobilization of Fission Iodine by Reaction with a Fullerene Containing Carbon Compound and Insoluble˚Natural Organic Matrix to help develop waste forms for the back end of fluorine-based separations processes. The laboratory collaborators are J. Laidler and G. Vandegrift (ANL)
16. Another international collaboration is ongoing for the Evaluation of Fluorapatite as a Waste-Form Material, with ANL and the Khlopin Radium Institute in St. Petersburg, Russia. The PI is Prof. D. Lindle, the laboratory collaborators are J. Laidler and G. Vandegrift (ANL), and the international collaborator is B. Burakov (KRI).

VI. ISU-IAC AAA PROGRAM

The ISU-IAC AAA Program was designed to benefit the National AAA Project and the University s goals to enhance accelerator infrastructure and research. Although ISU did not receive transfer of funding from the DOE until near the end of the fiscal year, much has been accomplished. ISU acquired equipment and initiated several projects that supported about 20 students, including one from UNLV and two from Tbilisi University in the Republic of Georgia. Three research projects are described below.

VI.A. Positron Annihilation for Materials Stress Analysis:

This part of the program is the development of the IAC materials stress determination technology. X-Ray induced positron annihilation spectroscopy (PAS) can provide highly penetrating probes for material characterization and defect analysis. This technology allows Doppler broadening measurements of spectra from positron annihilation in bulk materials such as those of interest in nuclear materials problems. In addition, this research has resulted in the demonstration of a new technique developed for positron lifetime measurements in bulk samples.

These new techniques for PAS use highly penetrating gamma-rays (bremsstrahlung from high-energy electrons) to create positrons inside the material via pair production. Collimated beams of gamma rays from small, pulsed 6-MeV electron Linacs are used to bombard the materials to generate positrons, which annihilate with the sample s electrons and emit 511-keV gamma radiation. Researchers at the IAC have also synchronized bremsstrahlung pulses with intense laser irradiation pulses to study dynamic structural changes in material as a result of thermally induced stress, where they have successfully measured stress/strain in engineering samples of several-cm thickness. These measurements have been completed on Steel, Aluminum, Zirconium and Silicon. In addition, they have developed another method using (p,gamma) reactions from a 2-MeV proton beam, which induce coincident gamma rays to perform positron life-time spectroscopy.

VI.B. Accelerator Driven Neutron Source:

An electron accelerator driven neutron source for performing dynamic reactivity measurements in multiplying and non-multiplying assemblies is being set up and tested. The accelerator will provide a pulsed neutron fluence of about 10^{11} neutrons per pulse and an average of 10^{13} neutrons per second. Building modifications on the IAC building are underway and will provide space for this facility that will be operational in early 2003. Photo-neutron production calculations and benchmark experiments have been performed for a number of accelerator target configurations. The experiments are being performed using the 20 electron linear accelerator at the Idaho Accelerator Center and the calculations were made using ACCEPT, PINP, MCNP, and MCNPX codes. Students determined that a high Z cylindrical target with a beam cavity, so the electron beam strikes the interior of the target, would provide the maximum neutron yield. This should produce a factor of ~2 increase in yield compared to surface bombardment, but measurement techniques must be refined to validate the calculations.

VI.C. Dose Conversion Coefficients:

Faculty and students in the Health Physics program at ISU are participating in this intercollegiate project with UNLV and other universities. It was described in Task 7 of the UNLV section of this report. The PI for this portion of the project is ISU Prof. Richard Brey, who is a member of the DCC working group. Several students are calculating dose coefficients and DCCs.

VII. OTHER ACTIVITIES AND EVENTS

VII.A. Winter Meeting of the American Nuclear Society

Students and others from the University Programs of the AAA Project dominated the first Student Mini-Conference that was held in conjunction with a national American Nuclear Society, and they played a substantial role in the main conference as well. The 2001 ANS Winter Meeting in November 2001 included 32 presentations that were based on AAA-sponsored university programs. Students gave 24 of the 43 presentations in the Mini-Conference, and project directors, faculty, and students gave 8 presentations during AccApp/ADTTA 01 Conference that was imbedded in the regular ANS Winter Meeting. A University of Michigan student gave one of those during a poster session, and the other seven were given in a special session during the AccApp/ADTTA 01 topical meeting that was imbedded in the Winter Meeting. The first described the overall AAA University Program,[23] and it was followed by presentations on the UNLV AAA UPP[21] and the AAA UFP.[6] Four technical presentations by faculty and students at UNLV,[22] the University of Michigan,[12, 14] and UC Berkeley[9] followed the programmatic presentations. In addition, three AAA project leaders gave overview presentations during the AccApp sessions of the Student Mini-Conference. About 20 UNLV students attended the ANS student Mini-Conference and the ANS Winter Conference, which included the AccApp/ADTTA 01 imbedded topical, and UNLV students accounted for 15 of the 44 papers presented in the Mini-Conference. The UNLV AAA Director also secured former Nevada governor Robert List as the keynote speaker for the banquet at the AccApp/ADTTA 01 conference. Seven AAA Fellows attended the ANS Mini-Conference, four made oral presentations.

These papers highlighted the progress and future direction of the university research to conduct academic research in support of the national effort to develop technology for the transmutation of waste from used nuclear fuel. Presentations that were given in the AAA sessions of the Student Mini-Conference are listed below (only the primary speaker is listed, and these presentations are not included in the endnote references):

Session 1:˚ AAA Accelerators, Fuels, and Systems Integration, Session Chair Denis Beller (LANL)

Opening Remarks:˚ AAA Overview, Denis Beller, Los Alamos National Laboratory
Modeling and Optimization of the Chemical Etching Process in Niobium Cavities, M. Holl, UNLV
Aspects of Advanced Accelerator Applications Fuel Cycle Scenarios, L. Outten, MIT
Transmuter Fuel Fabrication Processes, J .-K. Lee, UNLV
Design and Analysis for Melt Casting Metallic Fuel Pins Incorporating Volatile Actinides, X. Wu, UNLV
Methodology for Assessing the Proliferation Resistance of Accelerator Transmutation of Waste Technology Options, R. LeBouf, UT-Austin
Development of Dose Conversion Coefficients for Radionuclides Produced in Spallation Neutron Sources, J. Shanahan, UNLV
A nalysis of Waste Composition from ATW Fuel Cycle: Lead-Bismuth Eutectic (LBE) cooled fast reactor, M. Cheon, UC Berkeley
Source/Blanket Coupling and Thermal-Hydraulic Feedback, J. Platte, UM

Session 2:˚ AAA Separations, Session Chair James Laidler (ANL)

Opening Remarks:˚ James Laidler, Argonne National Laboratory
Developing Computer Models for Solvent Extraction Processes for Optimizing Flowsheets for Actinide Transmutation and Analyzing Their Technical Benefits/Liabilities and Proliferation Resistance, C.F. Bryant, UT-Austin
Development of a Systems Engineering Model of the Chemical Separations Process, L. Sun, UNLV
Improvement, Automation, and Modernization of AMUSE Code for the Chemical Separations Process, S. Munaga, UNLV
Criticality Analysis in Support of Transmutation, D.R. Lowe, UNLV
Criticality Assessment of Transuranic Waste Containers produced in the Electromechanical Treatment of High-level Radioactive Waste, J. Viggato, UNLV

Session 3:˚ AAA Transmuter and Reactor Physics, Session Chair Greg Van Tuyle (LANL)

Opening Remarks:˚ Greg Van Tuyle, Los Alamos National Laboratory
Investigation of Corrosion of Steel by Lead Bismuth Eutectic, D. Koury, UNLV
Modeling Corrosion in Oxygen Controlled LBE Systems with Coupling of Chemical Kinetics and Hydrodynamics, C. Wu, UNLV
High Temperature Deformation Characteristics of Alloy EP-823, M.M. Lewis, UNLV
Hydrogen-Induced Embrittlement of Candidate Target Materials for Applications in Spallation-Neutron-Target Systems, R. Kozak, UNLV
Transient Analysis of Source-Driven Subcritical Systems, V. Kulik, U of Michigan
Isotopic Transmutation and Destruction Rates in Various Neutron Energy Spectra, D.P. Griesheimer, U of Michigan

Radiation Transport Simulations in Support of Accelerator-Based Transmutation, L. Bakker, UNLV
Neutron Multiplicity Measurements of AAA Target/Blanket Materials, S.J. Curtis, UNLV

AAA-related papers in other Mini-Conference sessions:

Calculation of Internal Dose Conversion Factors for Selected Spallation Products, H. O. Wooten, Georgia Institute of Technology (Mr. Wooten s work led to the current UNLV-directed intercollegiate project)

Parametric Studies for Optimization of a Graphite-Moderated Molten-Salt Transmuter: Considerations Regarding Solubility Limits of Actinides and Fission Products in the Molten-Salt Fuel, E. Rodriguez-Vieitez, UC Berkeley

VII.B. Celebrity Visit provides AAA Visibility

In February of 2002, actor and philanthropist Paul Newman contacted me to ask what we could do with used nuclear fuel. I explained that many options had been explored and described several that are still open, like storage at an interim site such as the Goshute Reservation in Utah, disposal in a permanent repository such as Yucca Mountain, and recycling and transmutation. During one of several subsequent telephone calls, I mentioned a joint UNLV-DOE project to develop a public transit bus that is propelled by electricity from a hydrogen-fueled internal combustion engine. The opportunity to hear about the UNLV transmutation project, to see the hydrogen-fueled big-block V-8 engine (he s also a racecar driver and team owner), and to visit Yucca Mountain was irresistible. In March, Mr. Newman and Raymond Lamontagne (the Chairman of the Board of his Hole In the Wall Gang Camps for cancer-stricken children) spent two days in Southern Nevada. The Director and co-Director of the UNLV Transmutation Research Program gave presentations on nuclear waste disposal and on transmutation. They then visited the College of Engineering to learn about the hydrogen project and the racing engine shop where the engine was being tested on a dynamometer. On the second day of their visit, the Chief Scientist of the Yucca Mountain contractor and the Mayor of Caliente took Newman and Lamontagne on a personal guided tour of Yucca Mountain. This visit provided many opportunities to publicize the AAA project, because it was reported in the monthly newsletter of the UNLV Dean for Research, by the Nuclear Energy Institute, and by the American Nuclear Society. Subsequent follow-up activities and discussions provided further exposure for the program, including a dinner-debate that Newman and his wife, actress Joanne Woodward, organized for senior representatives from network and public television, prominent newspapers, and newsmagazines. I assembled the pro-nuclear side of this lively discussion, Environmental Defense organized the skeptics, and we gathered in the living room of their Fifth Avenue New York apartment to talk about disposition of used fuel and the future of nuclear power for a couple of hours.

VII.C. Publications and Presentations

In the short time that the ATW and AAA university programs have existed, many papers have been published and many presentations have been made. Some of these have been mentioned herein, while many others are cited in the references listed in the bibliography. University Programs presentations were made at the 2001 Winter Meeting of the ANS in Reno, Nevada[23] and at the 2002 Annual Meeting of the ANS in Hollywood, Florida.[24] Another presentation was made as part of a panel discussion on management of used nuclear fuel at the ANS Annual Meeting.[25] Colloquia were presented at The Ohio State University, University of Tennessee at Knoxville, University of Pittsburgh, ISU, Washington State University, and UNLV. University programs of the AAA project were also highlighted in a newsletter of the Accelerator Applications Division of the ANS.

VII.D. AAA University Workshop

In January of 2002 UNLV hosted a workshop for all university participants in the AAA Project. This workshop, which included about 70 participants, gave AAA management, laboratory technical staff, and faculty and students an opportunity to share research experience. It also gave many faculty and students a better feeling for the overall AAA Project goals and research activities, and gave management and technical staff a better feel for research capabilities at the AAA-supported universities.

VIII. FY03 PROJECTION AND FUTURE GROWTH

Expansion of academic collaborations for the AAA Project next year (FY03) and beyond depends on projected budgets. AAA Program management intends at the very least to continue the existing programs (UNLV TRP, ISU-IAC, existing Directed University Research, and Fellowships). However, an increased budget may allow these programs to expand and others to be added. Even without an increase in the AAA TRP budget, investments in infrastructure will decrease in future years such that additional funding may be available for student-based research. Thus, more than 50 students will be supported at UNLV even with level funding. The University Fellowship Program may expand to twenty students per year, may remain at the current level, or may be modified to include multi-year Ph.D. Fellowships.

A University Consortium for Transmutation Research (UCTR) is another new program that may be initiated in FY03. UNLV and URA initiated the UCTR with cooperation from about fifteen prominent universities with expertise in nuclear engineering, radiochemistry, and accelerator design and construction. The UCTR is intended to develop a strong university-run program to continue research and development of accelerator-driven transmutation and the eventual construction of a test facility. This test facility, if constructed, will be operated by the UCTR as a national or international user facility for academic research on transmutation of waste from the nuclear fuel cycle.

With growth in the UNLV TRP, ISU-IAC, AFC Fellowships, and Directed University Research, along with initiation of the UCTR, university collaborations could reach the order of $10 million per year by or before FY04.

IX. MEETING THE GOALS

In the introduction I described the goals of the AAA Project: to develop transmutation technology, to revitalize nuclear infrastructure, to provide a test-bed for advanced nuclear projects, and to resume an international leadership role. With the transition to the Advanced Fuel Cycle Program (AFC), our University research supports all of these goals while expanding on and leveraging other DOE/NE programs such as the Nuclear Energy Education Research Program (NEER), the Nuclear Energy Research Initiative (NERI) as well as International NERI (I-NERI), and reactor research programs such as Generation IV research. Much of the research and development that is being conducted for the AFC Project will support the development of Generation IV concepts and nuclear systems. With more than 115 students supported this year, and the expectation of even more in 2003, the contribution to the U.S. nuclear infrastructure is obvious. In addition, U.S. participation in international conferences will increase substantially as a result of the many research projects supported by AAA funding. This will demonstrate to the international community an expanding major role for the U.S. in this technology. As a prime example, the Student Mini-Conference that was held in conjunction with the Winter Meeting of the ANS in Reno, Nevada in November 2001 was dominated by AAA-supported student presentations (more than half of the oral papers were for AAA-sponsored research). We believe that AFC University Programs will continue to strongly support the mission and goals of the AFC Project.

X. SUMMARY

The Advanced Fuel Cycle (AFC) Program will require a large cadre of educated scientists and trained technicians in the next decade or more. Other applications of nuclear science and engineering also require increased academic and national infrastructure and student populations. The AFC Program Office has begun a multi-year program to involve university faculty and students in various phases of the Project to support the infrastructure requirements of nuclear energy, science and technology fields as well as the special needs of the DOE transmutation program. These AFC University Programs complement other DOE-NE programs such NEER, NERI and I-NERI, and reactor research programs like Gen-IV by connecting students to nuclear research projects in a wider variety of academic disciplines. In this paper we described university programs that have supported the AAA Project and that are supporting the R&D necessary for the AFC Project. These ongoing programs include the University Fellowship Program, the UNLV Transmutation Research Program, the Idaho Accelerator Center, Directed University Research, and other efforts. The AFC Project is well poised to contribute to the future education of nuclear scientists and engineers while conducting research that is essential to the success of the project. We expect AFC University Programs to grow substantially in the coming years.

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